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SOLAR RADIO OBSERVATIONS IN SUPPORT OF SKYLAB-A

by BRUCE L. GOTWOLS

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FINAL REPORT SUBMITTED TO THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
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Enclosure (1)
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SOLAR RADIO OBSERVATIONS
IN SUPPORT OF SKYLAB - A

by

Bruce L. Gotwols

Final Report Submitted to the
National Aeronautics and Space Administration

Grant No. : NGR 21-001-024
Period Covered: 1 Oct., 1972 - 31 March, 1974
NASA Technical Officer: Charles R. Baugher (MSFC)

Principal Investigator: Bruce L. Gotwols

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Introduction

This Final Report summarizes the research performed under NASA grant NGR 21-001-024, from 1 Oct., 1972 thru 31 March, 1974. This grant allowed the continuation of solar radio observations which had previously been funded with "in-house" research funds.

The research was performed under the direction of B. L. Gotwols, Antenna control, circuit construction, and routine cataloging of data were performed by R. J. Sneeringer.

Observations and Data Reduction

Observations commenced in November, 1972 (after a month of receiver improvement), and continued until the end of the last manned Skylab mission in February, 1974. As explained in our original proposal, it was not possible to obtain uninterruped sunrise to sunset coverage, due to the sharing of the 60 ft. antenna with other laboratory programs. Despite this limitation, 1408 hours of observations were obtained.

The spectra were recorded in real time, both on film and magnetic tape. The filming was performed with a continuous motion camera running at 0.8 in/min. This rate of film travel will only allow 0.2 s to be resolved, but this is sufficient to identify intervals which require further study with the full time resolution of 0.01s that is preserved on the magnetic tapes. High speed replays of all bursts were subsequently made at times which caused the least interruption to the observing program, i.e., during periods of exceptionally low solar activity, during the unmanned portions of the Skylab flight, etc.

A catalog of the observations is given in Appendix I. A similar catalog covering the period May, 1973 - February, 1974, has been submitted to World Data Center - A (NOAA), for inclusion in a catalog of ground based observations in support of Skylab.

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Equipment Modification

Our CRT display was modified so as to greatly improve the contrast obtainable on weak solar bursts, at the expense of decreasing the dynamic range displayed to 10 dB. The display was run in this high contrast mode throughout the period November, 1972 - February, 1974. For non-saturated filming of very strong bursts, the CRT controls are easily readjusted and the magnetic tape replay through the spectrograph display.

An automatic intensity calibration scheme (hourly) was constructed and installed in November, 1973. Up until this time intensity calibrations were performed manually once or twice a day.

Research Results

Preliminary reduction of our high time resolution observations has revealed the fact that there is often considerable curvature present at the low frequency extremity of the fast-drift bursts in our frequency range (see Figure 1). The entire burst occurs on a time scale of 0.5 s, so the detection of this curvature would have been impossible with the 0.2 s or greater scanning period of former studies. Stimulated by this new finding we are currently considering the following hypothesis: The majority of fast-drift decimetric wavelength bursts are the result of streams of electrons that are guided along closed magnetic field lines. This hypothesis appears to be capable of explaining the surprisingly loose correlation between type III bursts at decimeter and meter wavelengths. It can also account for the observation[1] that shorter lived decimeter wavelength type III bursts exhibit higher drift rates.

On the theoretical side, we have studied pulsating type IV solar radio bursts.[2] The most interesting result of this study

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1. Young, C. W., Specer, C. L. Moreton, G. E., and Roberts, J. A.: 1961, Astrophys, J., 133, 243.

2. Gotwols, B. L.: 1973, Solar Phys., 33, 475 (reprinted in Appendix II).

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was the way in which the Razin effect enhances the depth of modulation of the pulsations. Also of interest is the fact that when significant synchrotron self-absorption is present, the pulsations break up into two distinct bands which pulsate 180° out of phase with each other.

Colloboration with Other Groups

Our Data has been supplied directly to two of the investigators on Skylab. These are: Dr. E. B. Mayfield of the Aerospace Corporation (experiment S-056), and Dr. A. S. Krieger of AS & E (experiment S-54). Data has also been furnished to Dr. J. C. Brown who is currently visiting the Astronomical Institute at Utrecht.

A catalog of our observations during the first manned Skylab flight was included as part of a NOAA publication[3]. A complete catalog covering the entire Skylab flight has recently been submitted through the same channels.

Scientific Meetings and Publications

Gotwols, B. L. : "Pulsating Type IV Solar Radio Bursts", presented at the 140th meeting of the AAS, June 27, 1973, Columbus, Ohio. Abstract - BAAS, 5, 340, 1973

Gotwols, B. L. : "Solar Radio Pulsations", presented at IAU Symposium no. 57 on The Solar Corona, September 13, 1973, Surfers Paradise, Australia. Abstract - to be published in the Proceedings.

Gotwols, B. L. : 1973, Solar Phys. 33, 475 (reprinted in Appendix II).

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3. Coffey, H.: 1973, "Preliminary Catalog of Ground-Based Skylab-Coordinated Solar Observing Programs for the Period May 28 to July 26, 1973", World Data Center - A for Solar - Terrestrial Physics, NOAA, Boulder, Colorado.

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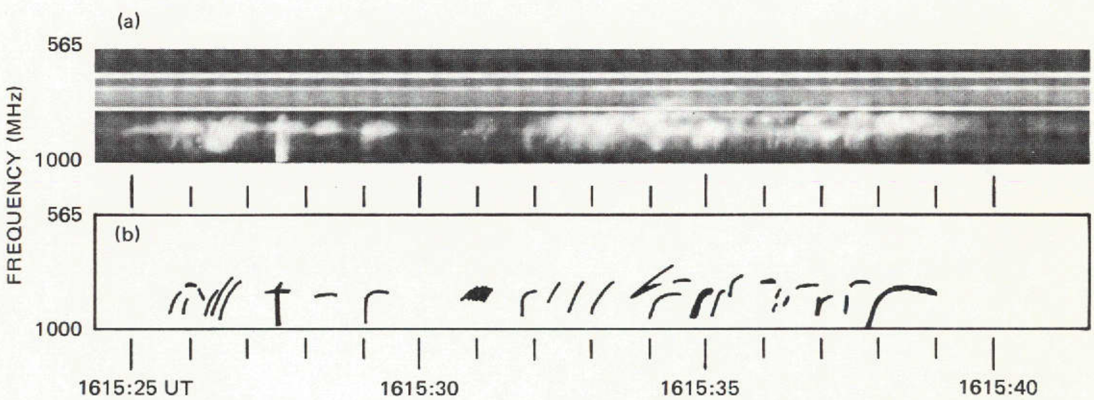

Fig. 1 Solar bursts recorded on 21 Nov. 197~~3~~2: (a) high time resolution dynamic spectra of fast drift bursts, many of which exhibit a low frequency turnover. Much detail has been lost in the process of reproduction. (b) schematic tracing of the original film from which Figure 2a was produced.

APPENDIX I

CATALOG OF SOLAR RADIO OBSERVATIONS

TAKEN AT THE APPLIED PHYSICS LABORATORY

November, 1972 - February, 1974

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
SILVER SPRING MARYLAND

A Guide for Classification of Solar Radio Bursts Observed with the APL Spectrograph[1] (565-1000 MHz)

TABLE I - Description of the various types of spectra

SPECTRAL TYPE	APL SYMBOL	DESCRIPTION AND COMMENTS
I	1	Storm bursts
II	2	Slow drift bursts
III	3	Fast drift bursts; $\dot{\nu} > 100$ MHz/sec
IV	4	Prolonged continuum
V	5	Brief continuum (normally following type III bursts)
-	6	Intermediate drift bursts; $\dot{\nu} \sim 30$-100 MHz/sec
UNCLF	UNCLF	Unclassified activity.

TABLE II - Symbols appended to the spectral type

SYMBOL	DESCRIPTION
P	Pulsations
G	Small group (< 10) of bursts
GG	Large group ($\geq$ 10) of bursts
C	Underlying continuum
U	U-shaped burst of type III
RS	Reverse-slope burst
DP	Drifting pair
N	Intermittent activity in this period

TABLE III - Intensity Scale

SYMBOL	FLUX DENSITY X10^{-22} Wm^{-2} Hz^{-1}
1	25 - 65
2	65 - 650
3	> 650

1 Gotwols, B. L. and Phipps J., 1972, Solar Phys. 26, 386.

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

NOV. 1972

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
15	2039	2054					
16	1329	1447					
	1510	2052					
17	1328	1725					
	1727	2016					
20	1520	1832	1933.2	1933.4	1	3G	
	1836	2053					
21	1340	2053	1347.8	1348.1	2	3G	
			1349.5	1349.7	1	3G	
			1351.0	1351.1	1	3G	
			1432.9	1435.5	3	3GG	
			1519.0	1519.4	2	3GG	
			1525.2	1525.3	1	3	
			1529.0	1536.4	2	3GG	
			1615.0	1616.2	3	3GG	
			1617.5	1619.7	3	3GG	
			1640.4	1640.9	2	3G	
			1642.2	1642.4	2	3G	
			1728.0	1728.1	1	3G	
			1730.1	1732.7	3	3GG	
			1756.3	1758.2	3	3GG	
			1817.5	1817.6	1	3G	
			1833.2	1833.4	2	3G	
			1850.1	1850.2	2	3G	
			1902.8	1903.9	3	3GG	
			1905.2	1905.8	2	3GG	
22	1342	1755	1422.6	1423.0	1	3G	
	2016	2051	1631.1	1631.6	1	UNCLF	
27	1311	1456					
	1525	2050					
28	1314	2013					
29	1305	1539					
	1623	2051					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

NOV. 1972

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
30	1301	2046	1522.0	1523.6	2	UNCLF	
			1711.7	1711.9	1	3G	
			1715.5	1715.5	1	3G	
			1916.4	1917.3	2	3GG	

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

DEC. 1972

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
05	1259	1358					
	1431	1606					
08	1953	2049					
11	1304	1634					
	1723	1910					
12	1308	1914	1615.0	1615.2	1	3G	LOW FREQ END
	1950	2006	1742.2	1742.6	3	3GRS	
13	1327	1456					
	1459	1516					
	1659	1900					
	2010	2113					
14	1257	1857					
	1901	2033					
15	1301	1427					
	1503	1539					
	1602	2009					
18	1257	1447					
	1518	2026					
19	1257	1416					
	1414	1443					
20	1331	1617					
	1711	1924					
	1956	2040					
	2104	2114					
21	1257	1525					
	1530	1856					
	1924	2050					
22	1304	1855	1321.6	1321.8	1	3G	
26	1301	1500	2015.1	2016.1	3	3G	
	1529	1945					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

DEC. 1972

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
26	2015	2054					
27	1301	1607					
	1703	1915					
	2013	2042					
29	1307	1522					
	1643	1819					
	1845	2048					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JAN. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
04	1306	1500					
	1519	1835					
	1906	2051					
05	1311	1434	1955.8	1957.2	3	3G	
	1920	2058					
08	1304	1617					
	1625	1634					
09	1537	1607					
17	1323	1546					
	1559	1710					
	2016	2043					
18	1321	1810					
	1925	2055					
19	1307	1735					
	1819	1947					
22	1414	1446					
	1454	1608					
	1645	1752					
	1826	1933					
	2006	2126					
23	1308	1725					
	1850	2050					
24	1307	1656					
	1725	2003					
	2034	2054					
25	1309	1937					
26	1307	1438					
	1613	1732					
	1806	2000					
	2032	2051					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JAN. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
29	1306	1745					
	1817	1937					
30	1339	1355					
	1949	2000					
31	1337	1646					
	1715	1732					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

FEB. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1304	1508	2017.6	2017.7	2	3U	
	1546	1616					
	1646	1734					
	1813	2038					
02	1305	1514					
	1618	1727					
	1758	1834					
	1914	1933					
	1950	2053					
05	1313	1538					
	1627	1737					
	1843	2053					
06	1305	1702					
	1735	1912					
	1945	1953					
09	1638	1713					
	1943	2050					
12	1424	1549	2038.3	2038.3	1	3	
	1615	1640					
	1703	2136					
13	1306	1517					
	1544	2050					
14	1257	1627					
	1656	2056					
15	1302	1615					
	1626	2 54					
16	1422	1527					
	1557	2106					
22	1511	1546					
	1656	1818					
	1847	2053					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

FEB. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
23	1321	1410					
	1445	1517					
	1546	1847					
	1921	1943					
	2010	2055					
26	1307	1528	2012.1	2013.3	1	UNCLF	
	1603	1702					
	1732	2054					
28	1305	1427	1733.0	1733.0	2	UNCLF	
	1459	1607	1735.4	1735.4	2	3G	
	1650	1805					
	1839	2035					
	2041	2050					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

MAR. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1324	1359					
	1429	1501					
	1602	1635					
	1708	1849					
02	1253	1432					
	1633	1743					
05	1314	1508					
	1552	1650					
	1711	2056					
08	1301	1348					
	1419	1532					
	1611	1647					
	1724	2047					
09	1518	1603					
	1636	1805					
10	1553	1644					
	1651	2030					
11	1306	1351					
17	1308	2009					
18	1312	2023					
19	1301	1321	1820.0	1820.0	1	3G	
	1346	1459					
	1621	2044					
22	1301	1327					
	1356	2051					
23	1326	1440	1404.8	1404.8	3	3G	
	1504	1634	1919.2	1919.4	1	UNCLF	
	1659	2041	2040.8	2041.2	3	3GG	
24	1304	1628	1314.1	1314.5	2	3G	

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

MAR. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
25	1310	2013	1616.8	1618.2	1	3GG	
30	1338	1453	1439.2	1439.4	1	UNCLF	
	1524	2042	1526.8	1530.1	3	3GG	
			1613.6	1614.2	2	3GG	
			1717.8	1718.2	1	UNCLF	

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

APR. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1740	1900	1747.3	1747.8	3	3GRS	
			1842.1	1842.3	2	3GU	

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

MAY 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
17	1749	2026	1749.0E	1750.5	2	3GG	
			1825.3	1827.1	2	3GG	
			1827.9	1828.5	1	3GG	
			1915.3	1917.9	3	3GG	
18	1203	1958	1527.4	1531.6	2	4P	
19	1210	1926					
20	1211	1936	1654.3	1654.4	1	3G	
21	1211	1653					
	1714	1749					
	1754	1852					
	1855	1955					
24	1345	1415					
	1424	1558					
	1601	1957					
25	1201	1635					
	1639	1816					
	1823	1959					
26	1155	1310					
	1322	1619					
	1639	1718					
	1725	1927					
27	1205	1543	1331.2	1331.6	1	3G	
	1550	1931	1606.2	1607.0	2	3GG	
28	1224	1929					
29	1638	1956					
31	1206	1957					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JUN. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1157	1955					
03	1231	1906					
04	1234	1453					
	1459	1751					
	1822	2019					
09	1231	1926					
10	1156	1918					
11	1219	1955					
12	1245	1516					
	1523	2000					
	2004	2047					
13	1201	1950	1322.0	1322.0	2	UNCLF	NARROW BANDWIDTH
14	1201	1432					
	1503	1953					
15	1208	1954	1409.3	1409.4	2	3G	
16	1224	1535	1422.0	1426.0	3	4U	
	1539	1926	1427.9	1428.4	2	3G	
17	1203	1926					
18	1220	1440					
	1510	1952					
21	1226	1507					
	1510	1956					
22	1159	1930					
23	1238	1852					
25	1214	1356					
	1433	1746					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JUN. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
28	1858	1920	1858.9	1859.7	2	3GG	
29	1202	1819	1310.0	1311.5	2	3G	
	1855	1931	1515.4	1517.4	2	4P	
			1908.6	1909.5	1	4	
30	1214	1918	1516.3	1518.8	3	3GG	

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JUL. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1210	1925					
02	1238	1530					
	1600	1953					
06	1155	1920					
07	1229	1449					
	1456	1930					
08	1217	1930					
09	1211	1752	1650.3	1650.3	2	3U	
	1820	1938					
12	1154	1251					
	1307	1432					
	1502	1805					
	1832	1916					
	1938	1954					
13	1156	1918					
14	1139	1845					
15	1131	1849					
16	1243	1334					
	1357	1649					
	1809	1947					
21	1129	1725					
22	1126	1237					
	1250	1955					
23	1226	1314					
	1352	1544					
	1547	1731					
	1825	2000					
26	1209	1458					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JUL. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
29	1128	1856	1309	1353	2	4	
30	1219	1600					
	1656	1726					
	1751	1829					
	1901	1955					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

AUG. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1155	1446					
	1729	1811					
	1911	1955					
02	1203	1329					
	1554	1732					
	1801	1955					
03	1244	1423					
04	1130	1842					
05	1132	1416					
	1423	1845					
06	1214	1712					
	1740	1920					
09	1151	1450	1151.0E	1151.8	3	3GU	
	1456	1727	1153.4	1154.1	1	UNCLF	
	1844	1945	1414.9	1415.9	2	3GU	
			1550.4	1552.6	2	3GGU	
10	1156	1657					
	1723	1748					
	1805	1826					
	1855	1943					
11	1134	1845					
12	1137	1847					
13	1218	1406					
	1412	1700					
	1803	1941					
16	1203	1533					
	1603	1952					
17	1157	1429					
	1436	1643					
	1820	1958					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

AUG. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
18	1149	1845					
19	1151	1244					
	1254	1844					
20	1217	1247					
	1318	1449					
	1637	1925					
23	1156	1418					
	1450	1524					
	1550	1812					
	1842	1954					
24	1201	1454					
	1519	1535					
30	1213	1955	1503.5	1503.8	1	3G	
31	1204	1219					
	1225	1941					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

SEP. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1204	1526					
	1747	1925					
02	1209	1219					
	1422	1535					
06	1215	1226					
	1346	1359					
	1422	1458					
	1622	1647					
	1746	1844					
	1930	1946					
07	1211	1320	1218.9	1223.4	2	3GG	
	1519	1937	1823.1	1823.3	1	UNCLF	
09	1217	1918					
10	1225	1443	1635.7	1635.7	2	3	
	1510	1748					
13	1215	1338					
	1341	1457					
	1615	1810					
	1818	1944					
14	1208	1423					
	1454	1938					
15	1206	1846					
16	1512	1727					
17	1217	1422					
	1502	1642					
	1657	1950					
20	1522	1638					
21	1206	1413					
	1442	1510					
	1601	2017					

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SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

SEP. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
22	1216	1404					
	1424	1924					
23	1220	1919	1749.9	1750.0	2	3G	
24	1339	1425	1759.1	1759.2	1	3G	
	1451	1708					
	1730	1813					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

OCT. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1242	1404					
05	1502	1846					
	1850	1946					
12	1224	1944	1450.8	1450.9	1	3	
13	1217	1927					
14	1216	1925					
15	1631	1755					
	1829	2000					
18	1251	1955					
19	1219	1332					
	1405	1930					
20	1227	1923					
21	1219	1830					
22	1243	1945					
25	1232	1318	1552.8	1553.0	1	3G	
	1352	1505					
	1540	1948					
26	1224	1447					
	1450	1945					
27	1224	1742	1550.0	1550.0	2	UNCLF	
			1555.5	1559.1	2	6GRS	
			1627	1633	2	4	
28	1227	1839					
	1845	1938					
	1950	2056					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

NOV. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
16	1308	1342					
	1408	1428					
	1511	1600					
17	1351	2023					
18	1308	1321					
	1324	1336					
19	1323	1639					
	1737	1838					
	1914	2026					
20	1333	1345					
	1405	1423					
	1708	1803					
	2014	2047					
24	1324	1351					
	1814	1847					
	1852	2020					
25	1303	1340					
27	1406	1914					
	1917	2106					
28	1431	2107					
29	1308	2031	1750.7	1750.7	1	3	
30	1305	1726					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

DEC. 1973

DATE	TIMES OF OBS. (UT) START	END	BURSTS START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1307	1916					
02	1318	2004					
03	1327	1602					
	1632	2040					
04	1319	1431	1349.0	1349.0	2	3	
	1623	2050	1949.6	1950.9	1	3G	
			1950.0	1950.1	1	3RS	
05	1323	1411					
	1424	1612					
	1620	1655					
	1745	1941					
	2008	2040					
06	1325	1714					
	1718	1930					
	2016	2046					
07	1305	2020					
08	1313	2015					
09	1332	2014					
10	1325	2030					
11	1330	1432					
12	1512	1545					
	1938	2110					
13	1318	1342					
	1521	1907					
	1910	2040					
14	1301	1600					
	1603	1734					
15	1258	1434					

JHU/APL

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

DEC. 1973

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
15	1820	2023					
16	1301	1411					
17	1619	1923					
	1927	2020					
18	1328	1949					
	2020	2048					
19	1322	1921					
20	1318	2030					
21	1314	1619					
	1624	1935					
22	1309	1922					
23	1303	1503					
	1542	1931					
24	1322	2110	1521.2	1521.3	3	3G	
26	1327	2050					
27	1715	2057					
28	1311	1906					
30	1335	1516					
	1553	2027					
31	1310	1540					
	1545	1600					
	1604	1959					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JAN. 1974

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1418	2122					
02	1343	2052					
03	1322	1908					
04	1316	1422					
	1432	1605					
	1620	1818					
	2009	2043					
05	1318	1945					
06	1330	2027					
07	1313	1935					
09	1429	1746					
10	1504	1957					
	2031	2046					
11	1319	1354					
	1449	1712					
	1716	1852					
12	1304	1822					
	1826	1947					
13	1311	1945					
14	1312	1726					
	1819	1942					
	2007	2040					
15	1307	1733					
	1759	1945					
17	1305	2100					
18	1304	1321					
	1935	2054					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JAN. 1974

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
19	1312	1949					
20	1320	1606					
	1614	1929					
21	1307	1335					
	1341	1640					
	1648	1748					
	1829	1841					
	1859	1921					
22	1305	1800					
	1835	1900					
	1928	2048					
23	1344	1522					
	1526	1702					
	1712	1832					
	1929	1946					
	1950	2055					
24	1310	1340					
	1344	1425					
	1505	1538					
	1617	1800					
	1829	2053					
25	1316	1411					
	1417	1548					
	1702	1729					
	1758	2040					
26	1309	1937					
27	1305	1942					
28	1304	1738					
	1809	2029					
30	1417	1909					
	1912	2105					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

JAN. 1974

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
31	1819	1956					

SOLAR RADIO EMISSION
SPECTRAL OBSERVATIONS (565-1000 MHZ)

FEB. 1974

	TIMES OF OBS. (UT)		BURSTS				
DATE	START	END	START(UT)	END(UT)	INT.	TYPE	REMARKS
01	1303	1709					
	1812	2038					
02	1308	1552					
	1558	2033					
03	1324	2034					
04	1303	1733					
	1801	2029					
05	1302	1411					
	1428	1654					
	1729	1845					
	1849	2039					
06	1332	1439					
	1444	1628					
	1658	2039					
07	1305	1600					
	1628	2040					

APPENDIX II

SOLAR PHYSICS

REPRINT

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A Journal for Solar Research and the Study of Solar Terrestrial Physics

PULSATING TYPE IV SOLAR RADIO BURSTS

B. L. GOTWOLS

The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Md. 20910, U.S.A.

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PULSATING TYPE IV SOLAR RADIO BURSTS

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Abstract. Several models for pulsating type IV radio bursts are presented based on the assumption that the pulsations are the result of fluctuations in the synchrotron emission due to small variations in the magnetic field of the source. It is shown that a source that is optically thick at low frequencies due to synchrotron self-absorption exhibits pulsations that occur in two bands situated on either side of the spectral peak. The pulsations in the two bands are 180° out of phase and the band of pulsations at the higher frequencies is the more intense. In contrast, a synchrotron source that is optically thin at all frequencies and whose low frequency emission is suppressed due to the Razin effect develops only a single band of pulsations around the frequency of maximum emission. However, the flux density associated with the later model would be too small to explain the more intense pulsations that have been observed unless the source area is considerably larger than presently seems reasonable.

1. Introduction

One interpretation of the quasi-periodic fluctuations (pulsations) that are occasionally seen in type IV radio bursts is that they are caused by changes in the synchrotron emission of a source which result from fluctuations in the background magnetic field. This variable magnetic field is attributed to a standing magnetohydrodynamic wave that is set up in a magnetic flux tube (Rosenberg, 1970). In this paper the correctness of this model is assumed and it is shown how the presence of a low frequency cutoff of the type IV spectrum qualitatively affects the pulsations. The following four cutoff mechanisms and their effect on the pulsations will be explored: (1) synchrotron self-absorption, (2) Razin effect, (3) gyro-synchrotron absorption by thermal electrons, and (4) collisional (free-free) absorption.

2. Theory

The equations for the synchrotron emissivity and absorption coefficient are greatly simplified when the radiating electrons have attained ultra-relativistic energies. All of the results obtained in this section are for an isotropic power law differential energy spectrum in the ultra-relativistic limit. The modal dependence of the various quantities will be ignored. It will be shown in later sections that the results so obtained are in qualitative agreement with more realistic numerical computations.

Consider an electron energy spectrum

$$N(\gamma)\,\mathrm{d}\gamma \sim \gamma^{-\Gamma}\,\mathrm{d}\gamma, \qquad \Gamma > 0, \tag{1}$$

where γ is the electron Lorentz factor. Assuming a very tenuous plasma, the synchrotron absorption coefficient associated with this energy spectrum is (Ginzburg and Syrovatskii, 1964)

$$\kappa_\nu \sim B^{n-1}\nu^{-n}, \qquad n = (\Gamma + 4)/2, \tag{2}$$

and the volume emissivity is

$$j_\nu \sim B^{m+1}\nu^{-m}, \qquad m = (\Gamma - 1)/2, \tag{3}$$

where B is the magnetic field of the source. The power law dependence exhibited in Equations (2) and (3) retains its usefulness even for a mildly relativistic population of electrons. In that case, however, m and n become slowly varying functions of frequency which must be determined by numerical computation.

The intensity emergent from a volume of depth L and with uniform magnetic field is given by

$$I_\nu = \frac{j_\nu}{\kappa_\nu}(1 - e^{-\kappa_\nu L}). \tag{4}$$

In the limit of large optical depth ($\kappa_\nu L \gg 1$), Equation (4) reduces to

$$I_\nu = \frac{j_\nu}{\kappa_\nu} \sim B^{-(n-m-2)}\nu^{n-m} \sim B^{-0.5}\nu^{2.5}, \tag{5}$$

and for the optically thin case ($\kappa_\nu L \ll 1$), we have

$$I_\nu = j_\nu L \sim B^{m+1}\nu^{-m}. \tag{6}$$

Assuming $\Gamma > 1$, we see from Equation (6) that in the optically thin portion of the spectrum the intensity is a monotonically increasing function of the magnetic field. On the other hand, in the optically thick regime Equation (5) shows that an increase in magnetic field causes a *decrease* in the emergent intensity. Thus, a periodic variation of the magnetic field will cause periodic variations in the synchrotron intensity, with these variations undergoing a 180° phase shift across the peak in the spectrum.

The band of pulsations in the optically thick regime are insensitive to the steepness of the electron energy spectrum. However, for the optically thin band of pulsations, steeper energy spectra give rise to more intense pulsations. Similarly, the steep spectrum associated with an anisotropic momentum distribution will favor the generation of intense pulsations.

Now consider the case where the density of the cold background plasma is sufficient to cause the index of refraction to be slightly less than unity. As Ramaty (1969) has shown, this causes both the synchrotron emissivity and absorption coefficient to be significantly depressed (Razin effect) at frequencies less than ν_r, where

$$\nu_r = 0.7\nu_p^2/\nu_b. \tag{7}$$

The synchrotron emissivity and absorption coefficient remain unaffected by the ambient medium when $\nu \gg \nu_r$. Here ν_b is the nonrelativistic gyro frequency and ν_p is the electron plasma frequency. We shall assume that the source is optically thin at all frequencies in order to clearly separate effects due to the cold background plasma from the previously discussed case of an optically thick source. In the absence of the Razin effect, Equation (6) correctly describes the dependence of intensity on the magnetic field. Thus an increase in the magnetic field results in an increase in intensity. When the Razin effect is present, an increase in the magnetic field causes the Razin turnover frequency (ν_r) to decrease and thus leads to a lessening of the Razin suppression, particularly at frequencies such that $\nu < \nu_r$. Therefore, both effects act in the same direction, so we may qualitatively predict that in a Razin suppressed source the intensity is a stronger function of the magnetic field than is predicted by Equation (6). Further, there will be only a single band of pulsations that are enhanced in the vicinity of the Razin turnover frequency.

Brief consideration will now be given to two other mechanisms which give rise to a low frequency turnover in the type IV spectrum. In both cases considered below we assume that the synchrotron self-absorption is small. As Ginzburg and Zheleznyakov (1959) have shown, gyro-resonance absorption by thermal electrons at the first few harmonics of the local gyro-frequency can significantly absorb the low-frequency synchrotron emission. When $\nu > \nu_b$, the intensity observed at the Earth can be written

$$I_\nu = j_\nu L e^{-\tau_g(\nu)}, \qquad \tau_g(\nu) = \int_0^{1\,\mathrm{AU}} \kappa_g(\nu, h)\,\mathrm{d}h, \tag{8}$$

where κ_g is the gyro-resonance absorption coefficient. With the reasonable assumption that the coronal magnetic field decreases slowly with increasing altitude, absorption at the second and higher order harmonics will occur far above the source. Thus it is unlikely that the magnetic field in these layers will be oscillating coherently with the magnetic field in the postulated magnetic flux tube. However, at a frequency equal to the gyro frequency, the thermal electrons responsible for the gyro-resonance absorption reside in the source itself so that some *relative* enhancement of the pulsating component can be expected. This absorption at the fundamental is so intense, however, that the absolute value of the observed intensity will be small.

Free-free absorption by thermal electrons can also significantly modify the intensity of a synchrotron source. Neglecting the thermal emissivity in comparison to the synchrotron emissivity, and assuming negligible synchrotron self-absorption, the intensity from a homogeneous source of depth L can be written (Ramaty and Petrosian, 1972)

$$I_\nu = \frac{j_\nu}{\kappa_{\mathrm{ff}}}\left(1 - e^{-\kappa_{\mathrm{ff}} L}\right), \qquad \kappa_{\mathrm{ff}} = 10^{-2}\,\frac{N^2}{\nu^2 T^{3/2}}\left[17.7 + \ln\left(T^{3/2}/\nu\right)\right], \tag{9}$$

where κ_{ff} is the free-free absorption coefficient, N is the number density of thermal electrons, and T is the temperature. Since the free-free absorption coefficient is not a function of the magnetic field, the only effect this mechanism can have is to multiply the synchrotron emissivity by a frequency dependent weighting factor. Thus the *relative* amplitude of any pulsations present in the synchrotron emissivity are left unchanged.

3. Model for a Pulsating Self-Absorbed Source

In this section and the section to follow, we present the results of numerical computations of gyro-synchrotron radiation which follow the formulation given by Ramaty (1969) and therefore need not be repeated here. However, note that we have made the correction* $\partial(\mu v)/\partial v \rightarrow \mu$ (μ is the index of refraction) as given by Trulsen and Fejer (1970). Corrections to the emissivity and absorption coefficient to account for the phase and group velocity in a magnetoactive plasma not being (in general) parallel have been neglected. These corrections are only important when the index of refraction becomes highly anisotropic, such as at frequencies extremely close to the plasma cutoff frequency. The approximate forms for the Bessel functions given by Wild and Hill (1971) have been used in the calculations. In all of the numerical examples we have assumed an isotropic power law in *kinetic* energy with a low energy cutoff at 100 keV and an exponent of -3. This exponent is a typical value for the energy spectra as deduced from impulsive X-ray bursts (Kane, 1971).

As a check on the accuracy of our computations several of the examples published

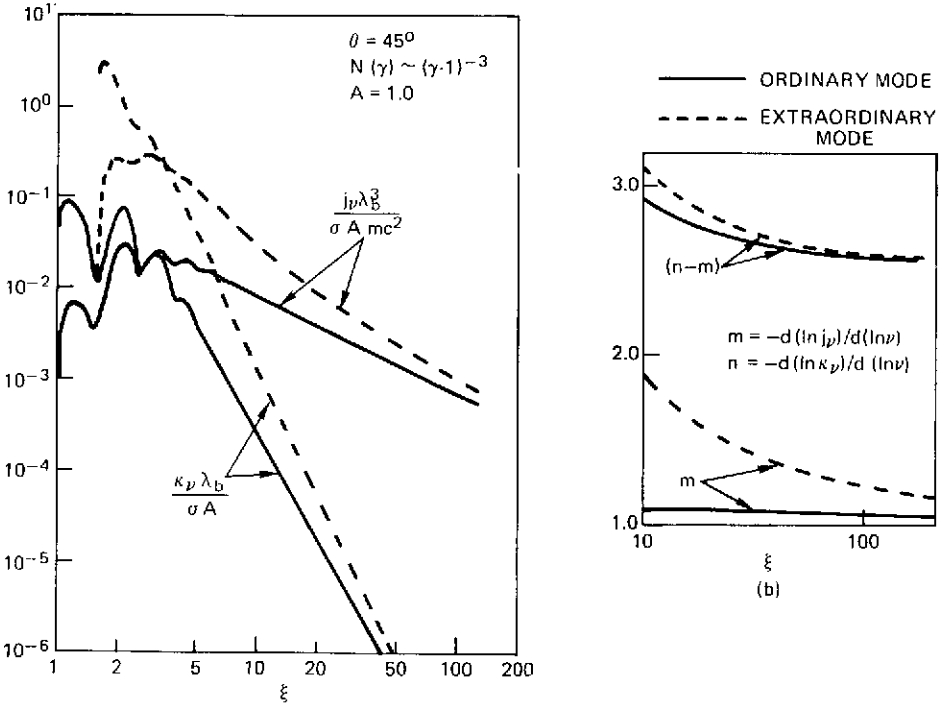

Fig. 1. (a) Gyro-synchrotron absorption coefficient and volume emissivity plotted as dimensionless ratios; (b) log-log slopes of the curves in Figure 1a.

* It is fortuitous that this error is absent in Ramaty's (1969) *numerical* calculations (Ramaty and Petrosian, 1972).

by Ramaty (1969) were recomputed. In each case that was checked, good agreement between the two independent computations was obtained.

In Figure 1a we have plotted as dimensionless ratios the absorption coefficient and volume emissivity for a homogeneous gyro-synchrotron source when viewed at an angle (θ) of 45° between the magnetic line of force and the line of sight to the observer. Here σ is the ratio of the number density of thermal electrons to the number density of nonthermal electrons, mc^2 is the rest energy of an electron and λ_b, A, and ξ are defined by

$$\lambda_b = c/v_b, \qquad A = v_p^2/v_b^2, \qquad \xi = v/v_b. \tag{10}$$

The log-log slopes of the curves of Figure 1a are plotted in Figure 1b in a way which is convenient for insertion into Equations (5) and (6). It is seen that the plotted values are slightly higher than the ultra-relativistic limit values of $m=1.0$ and $n-m=2.5$. Although Figures 1a and 1b were computed for $A=1$, similar calculations show that these curves also hold with good accuracy for any value of $A \lesssim 1$, when $\xi \gtrsim 4$. This is because the Razin turnover frequency occurs at $\xi \simeq 0.7A$; thus the Razin suppression is negligible when $\xi \gtrsim 4$ and $A \lesssim 1$. These curves are therefore useful in constructing alternate models to the one presented below.

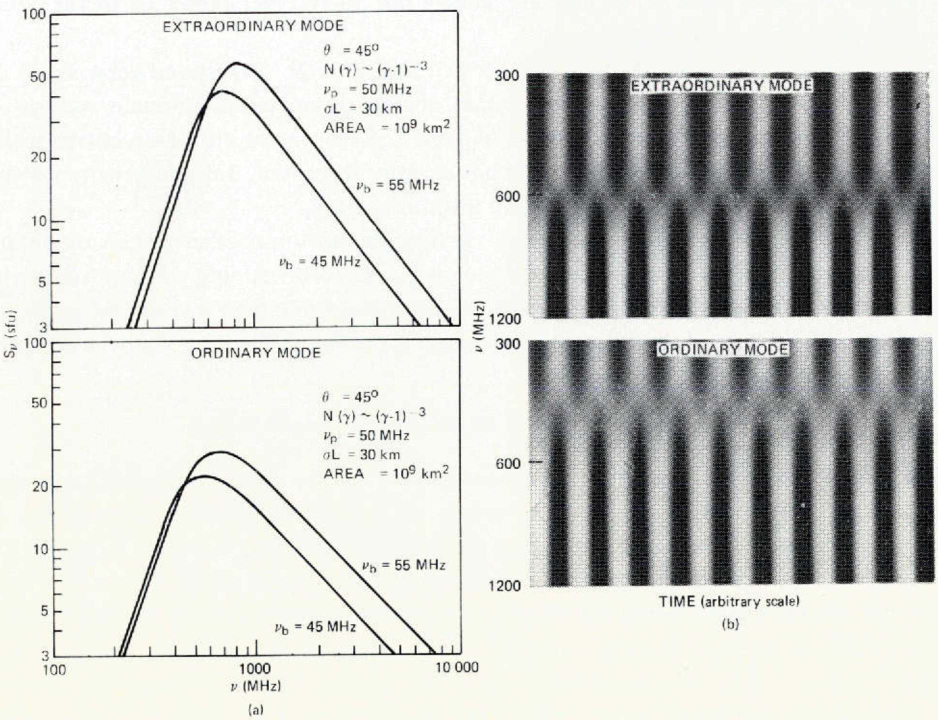

Fig. 2. Flux density from a pulsating gyro-synchrotron source. The flux density is in solar flux units where 1 sfu $= 10^{-19}$ erg s^{-1} cm^{-2} Hz^{-1}. (a) Spectrum for two extreme values of the magnetic field; (b) computer generated dynamic spectra showing complementary pulsations. The intensity has been logarithmically compressed and the time-averaged intensity at each frequency has been subtracted.

In Figure 2a we have plotted the flux density ($S_\nu = I_\nu \Delta\Omega$) which would be measured at the Earth for a radio source with a cross-sectional area of 10000 by 100000 km. The indicated thickness parameter (σL) is consistent with $\sigma = 3 \times 10^{-3}$ and $L = 10000$ km. This geometry is approximately the same as that suggested by McLean *et al.* (1971). The flux densities which are plotted correspond to a $\pm 10\%$ variation in the magnetic field. In the optically thin portion of the extraordinary mode spectrum ($\nu = 1500$ MHz) this gives a variation in flux density of $+26\%$ and -23%, whereas in the optically thick regime ($\nu = 500$ MHz) the flux density varies by -10% and $+13\%$. A larger peak flux density than that shown can be obtained by increasing the σL parameter.

The appearance of these pulsations on a dynamic spectrograph has been simulated in the computer drawn pictures shown in Figure 2b. In generating these pictures we have allowed the magnetic field to vary sinusoidally with an amplitude that is 10% of the average field. The long term time-average of the flux density at each frequency has been subtracted, in analogy to the sensitive technique used by the Utrecht group to observe pulsations (De Groot, 1970). The separation of the pulsations into two distinct bands which pulsate 180° out of phase is clearly evident in Figure 2b. We shall refer to these two bands as complementary pulsations. In this simulation no attempt has been made to include the effects due to receiver noise, or to the solar flux density of thermal origin.

The two characteristic polarizations plotted in Figure 2b correspond very nearly to opposite circular polarizations (QL regime). If linearly polarized antennas were used to receive this radiation, the extent in frequency of the transition region between the complementary pulsations would be considerably increased. Inhomogeneity of the magnetic field of the source would have a similar effect.

It is interesting to note that the time varying absorption coefficient can modulate the intensity from an external source which happens to be shining through the gyro-synchrotron source. However, this effect will be observable over a very limited range in frequency because of the extremely steep cutoff caused by the exp $(-\kappa_\nu L)$ weighting factor.

4. Model for a Pulsating Razin-Suppressed Source

The effect of a $\pm 10\%$ variation in magnetic field on the absorption coefficient and volume emissivity in a synchrotron source with significant Razin suppression is shown in Figure 3. This figure shows that the maximum absolute variation in emissivity occurs near the peak in the spectrum, while the largest relative variation occurs where the spectrum is rapidly being cut off due to the Razin suppression. At the peak of the extraordinary mode emissivity curve a $\pm 10\%$ variation in magnetic field causes a $+66\%$ and a -43% change in emissivity. Thus upon first consideration, it appears that pulsations are most easily generated in Razin suppressed sources. However, for the model shown, if the source is to remain optically thin at all frequencies, we must require that $\sigma L \lesssim 7 \times 10^3$ cm. Using this upper limit for σL, a source with the same geometry as assumed in the previous section would yield a peak flux density of only

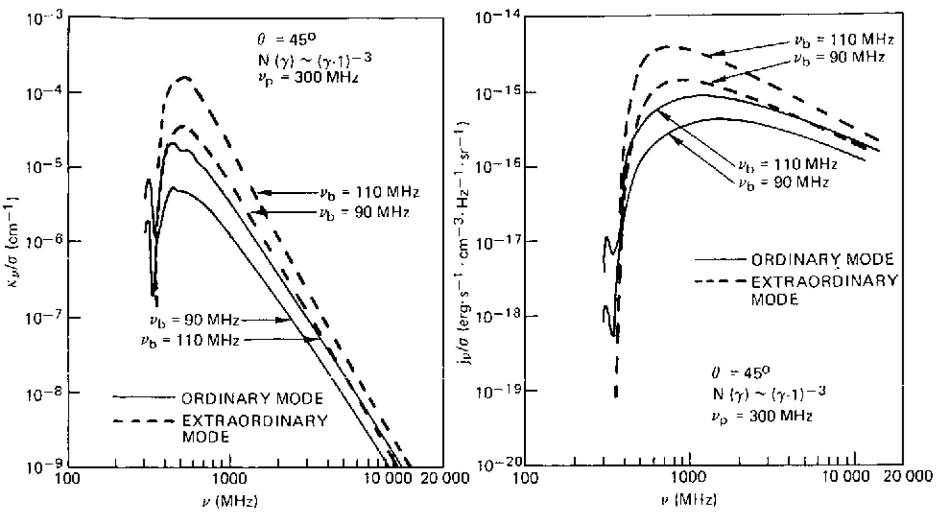

Fig. 3. Gyro-synchrotron absorption coefficient and volume emissivity for a Razin-suppressed source.

12 solar flux units (sfu). This is far below the estimate of 1000 sfu pulsations reported by Rosenberg (1970) and the 400 sfu pulsations observed by Gotwols (1972). Significantly more flux density is not available from our model at any θ. This is because *both* the emissivity and the absorption coefficient increase as θ approaches 90°. Thus in order for the source to remain optically thin, the upper limit on σL must be lowered, thereby at least partially offsetting the increase in the emissivity. On the other hand, if the cross-sectional area of the source is much larger than assumed above, the theoretical flux density can equal the observed value. However, such a large shallow source could certainly not be called a magnetic flux tube and it is very difficult to imagine how the magnetic field could be made to fluctuate coherently throughout such a large volume.

5. Summary and Conclusions

Four mechanisms that cause a low frequency turnover of type IV spectra and their effect on pulsations have been considered. When $\nu > \nu_b$, free-free and gyro-resonance absorption by thermal electrons cause a frequency dependent weighting of the gyro-synchrotron spectrum. The *relative* amplitude of the pulsations is left unchanged.

The presence of self-absorption or Razin suppression significantly affects the generation of pulsations. For a pulsating gyro-synchrotron source with significant self absorption we have found that the dynamic spectrum of the pulsations is split into two distinct parts which pulsate 180° out of phase with each other (complementary pulsations). Those pulsations which occur in the optically thin part of the spectrum will be larger than their low frequency counterparts. On the other hand, the pulsations in an optically thin Razin-suppressed source show only a single band of pulsations. Although the Razin effect enhances the relative amplitude of the pulsations, the absolute flux increase will be quite small unless the source is much larger than seems reasonable for a discrete magnetic flux tube.

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